

AL/HR-TP-1995-0030



**ASSESSMENT OF CONFIGURATIONAL KNOWLEDGE  
OF NATURALLY- AND ARTIFICIALLY-ACQUIRED  
LARGE-SCALE SPACE**

**J. Wesley Regian  
Robert M. Yadrick**

**HUMAN RESOURCES DIRECTORATE  
TECHNICAL TRAINING RESEARCH DIVISION  
7909 Lindbergh Drive  
Brooks AFB, Texas 78235-5352**

19960130 024

November 1995

Interim Technical Paper for Period October 1993-December 1993

Approved for public release; distribution is unlimited.

**AIR FORCE MATERIEL COMMAND  
BROOKS AIR FORCE BASE, TEXAS**

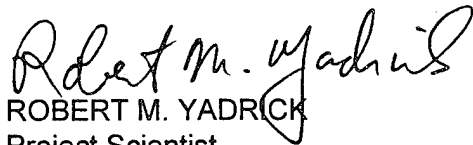
**ARMSTRONG  
LABORATORY**

## NOTICES

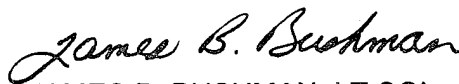
When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation; or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Office of Public Affairs has reviewed this paper, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This paper has been reviewed and is approved for publication.

  
ROBERT M. YADRICK  
Project Scientist

  
R. BRUCE GOULD, Ph.D.  
Technical Director

  
JAMES B. BUSHMAN, LT.COL., USAF  
Chief, Technical Training Research Division  
Human Resources Directorate

Please notify this office, AL/HRPP, 7909 Lindbergh Drive, Brooks AFB TX 78235-5352, if your address changes, or if you no longer want to receive our technical reports. You may write or call the STINFO office at DSN 240-3853 or commercial (210) 536-3853.

# REPORT DOCUMENTATION PAGE

Form Approved

OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE November 1995	3. REPORT TYPE AND DATES COVERED Interim Technical Paper - October 1993-December 1993	
4. TITLE AND SUBTITLE  Assessment of Configurational Knowledge of Naturally- and Artificially-Acquired Large-Scale Space			5. FUNDING NUMBERS  PE - 61102F PR - 2313 TA - T2 WU - 18	
6. AUTHOR(S)  J. Wesley Regian Robert M. Yadrick				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  Armstrong Laboratory Human Resources Directorate Technical Training Research Division 7909 Lindbergh Drive Brooks AFB TX 78235-5352			8. PERFORMING ORGANIZATION REPORT NUMBER  AL/HR-TP-1995-0030	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Approved for public release; distribution is unlimited			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  We report on two studies designed to explore subjects' performance in learning and assessing knowledge of artificial- and real-world environments. Experiment 1 established norms for supporting materials used in Experiment 2. Subjects in Experiment 2 learned an artificial (computer-based) environment that was either randomly- or prototypically-configured then performed several tasks intended to assess their configurational knowledge of the environment. The results showed that subjects were able to derive configurational knowledge from either random or the prototypical condition. However, configurational knowledge was better in the random condition than in the prototypical condition. We also found that subjects' configurational knowledge was, in general, functionally similar to their knowledge of a real-world environment.				
14. SUBJECT TERMS Assessment Spatial learning Spatial reasoning			15. NUMBER OF PAGES 32	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT  UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE  UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT  UNCLASSIFIED	20. LIMITATION OF ABSTRACT  UL	

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89) Prescribed by ANSI Std Z-39-18  
298-102 COMPUTER GENERATED

## Table of Contents

PREFACE.....	iv
INTRODUCTION.....	1
EXPERIMENT 1.....	4
EXPERIMENT 2.....	8
REFERENCES.....	23

## List of Tables

Table 1. Likelihood Ratings for the Amusement Park.....	7
Table 2. Likelihood Ratings and Recall Levels.....	15
Table 3. Correlations Between Performance Measures.....	17
Table 4. Average Correlations Between Original Data and Solutions.....	18

## List of Figures

Figure 1. MDS Solution for the Amusement Park.....	8
Figure 2. Prototypical Amusement Park Configuration.....	11
Figure 3. Grid Map of the University of Pittsburgh.....	18
Figure 4. Real-World MDS Solution, All Subjects.....	19
Figure 5. MDS Solution for Prototypical Amusement Park.....	20
Figure 6. MDS Solution for Random Amusement Park.....	20

## PREFACE

This report is based on a dissertation submitted by the first author to the Department of Psychology, University of California at Santa Barbara, in partial fulfillment of the requirements for the Ph.D. degree. The second author updated the literature review and rewrote the dissertation in its present form. The pronoun "we" is used throughout because it seems appropriate for an article with two authors, but the first author alone designed and conducted all three studies.

# ASSESSMENT OF CONFIGURATIONAL KNOWLEDGE OF NATURALLY- AND ARTIFICIALLY-ACQUIRED LARGE-SCALE SPACE

## INTRODUCTION

Researchers generally agree that environmental spatial learning proceeds from initially isolated landmark knowledge to route knowledge based on the temporal ordering of landmarks. This develops into knowledge of spatial relationships among landmarks, and finally into knowledge of multiple routes organized into configurations (Siegel & White, 1975; Allen, 1979). This progression reflects an increasingly complex knowledge of the environment and an increasing coordination of initially piecemeal information. Configurational knowledge is of particular interest because it is the most generally useful type of environmental knowledge, increasing in quality and usefulness with greater exposure to and experience with an environment (Foley & Cohen, 1984; Herman, Cachuela, & Heins, 1987; Herman, Blomquist, & Klein, 1987).

There are potentially important differences between learning a large-scale environment by navigating through it or by studying a small-scale map of it. For one thing, a small-scale representation usually can be viewed at one time from a single vantage point, whereas large-scale space generally extends beyond one's immediate view. In addition, real-world environments are usually viewed from within, rather than from the birds-eye viewpoint characteristic of small-scale spaces. Finally, exploring real environments typically involves whole-body movements, rather than simply eye, head, and neck movements. It is possible that different processes involved in learning large- and small-scale space are related to various functional differences researchers have reported in learning or performance measures over the years (e.g., Evans & Pezdek, 1980; Thorndyke & Hayes-Roth, 1982; Presson & Hazelrigg, 1984; Presson, DeLange, & Hazelrigg, 1989). Presson and Hazelrigg (1984) suggested a fundamental process difference between "primary" and "secondary" spatial learning. In their view, learning small-scale space, including learning maps that represent larger spaces, is a secondary activity which results in a detailed, picturelike image. What is learned, however, is a set of spatial symbols which must be translated before they can be used for such tasks as making orientation decisions. McNamara, Altaribba, Bendele, Johnson, and Clayton (1989) discussed the differences found in a number of studies of priming effects in spatial memory, and decided that the key to understanding these differences is a process of "decontextualization" that takes place during navigation. This is essentially an elaboration of Evans and Pezdek's (1980) "multiple vantage point" explanation, and likewise appears closely related to Sholl's (1987) belief that cognitive maps are a form of "orienting schema", which result when people experience the optical flow patterns that come from movement through an environment. No such information is presumed to be available from maps.

Sholl apparently doesn't consider configurational knowledge to qualify as a cognitive map unless primary learning is involved. Cognitive maps, by this definition, provide direct access to configurational information which must be translated or computed if it was originally acquired via secondary learning. We refrain from using the term "cognitive map" in favor of "configurational knowledge", which we intend as a neutral term, partly because there is no consensus among researchers about what the term "cognitive map" means. For our purposes, we are only concerned about whether configurational knowledge is functional and useful, that is, whether it can be accessed and used to determine the distance, direction, or route from one location to another, much as a physical map can be consulted. We are not interested in whether this knowledge is immediately available or isomorphic to a two-dimensional cartographic map. Neither do we intend to explore the issue of how spatial information is coded (Kosslyn, 1980; Pylyshyn, 1984). The primary goal of the current research is to determine the extent to which artificially-acquired configurational knowledge is functionally similar to naturally-acquired configurational knowledge. Our tactical approach to this involves the detailed examination of individuals' ability to develop, maintain, and utilize knowledge relevant to the locations of objects in natural and artificial environments, especially the spatial configuration of these locations.

### **Acquisition of Configurational Knowledge**

At present, our understanding of the process of translating or mapping information between modalities remains poor. What is clear, however, is that a person can acquire some type of configurational knowledge from a variety of experiences.

#### **Natural Acquisition Studies**

Studies of naturally-acquired configurational knowledge typically assess existing knowledge of a real-world environment (Herman, Kail, & Siegel, 1979.; Shute 1984; Tversky, 1981), or require people to move through unfamiliar environments (Levine, Jankovic, & Palij, 1982; Lindberg & Garling 1981a, 1981b). One gives up a certain amount of control over variables like the extent and nature of exposure to the environment when assessing existing knowledge. Variables of this sort can be partially controlled by blocking on the amount of time subjects have operated in an environment, by selecting subjects who are likely to be comparable with regard to their agenda in the environment (e.g., Evans, Marrero, & Butler, 1981), by taking subjects to an unfamiliar environment and carefully controlling their actions (e.g., Golledge, Smith, Pellegrino, Doherty, & Marshall, 1985), or by creating an artificial environment that is still naturally acquired in the sense that subjects learn by actually moving through it (Lindberg and Garling, 1983; Gauvain and Rogoff, 1986). Such environments are so rich in information that it is inevitable that different individuals will attend to different aspects

of the environment. In some cases, this presents control problems; in others, such as the Golledge et al. (1985) study, the point is to understand what aspects of the environment are selected during learning.

### **Acquisition from Physical Maps**

Few studies have explicitly related map learning to real-world environments. Wetherell (1979) compared memory for maps to memory for verbal directions in a real-world route-navigation task, and found that although people can use previously-learned maps for route navigation, previously-learned verbal directions are better for the purpose. This supports the idea that route navigation is initially more procedural than spatial, an idea also supported by Hazen, Lockman, and Pick's (1978) finding that route knowledge has asymmetric qualities, such as not being easily reversed. Stasz (1979) and Thorndyke and Stasz (1980) were able to differentiate good and poor learners of spatial attributes by their use of imagery, pattern encoding and relational encoding, although they made no empirical connection to configurational knowledge of large-scale space.

### **Acquisition From Verbal Descriptions**

There are indications in the literature that verbal acquisition of configurational knowledge is possible (Glushko & Cooper, 1978; Mani & Johnson-Laird, 1982; Easton & Bentzen, 1987). Foos (1980) provided an explicit demonstration of learning from relational encoding by reading subjects sets of brief sentences such as: "The bank is east of the lake. The school is south of the bank.", and was able to demonstrate the construction of simple configurational knowledge from text. His purpose was to test and extend to spatial information a general theory of how linear orderings are retained and processed in short-term memory, and his study left unanswered questions about whether subjects can form complex knowledge under conditions where much of the required information is available to the subject at the same time and few restrictions are placed on study time.

Franklin and Tversky (1990) proposed that "mental models derived from text are similar to representations of real-world experience" (page 63), and demonstrated convincingly that people can acquire detailed configurational knowledge from text. They contended that construction of an elaborate mental model can substitute for direct experience. It seems likely that under such conditions individual learning strategies would be more important than basic memory processes.

Although the relationship between acquisition from verbal descriptions and acquisition from maps is not clear, it appears likely that the relationship is one of mutual mediation or other form of facilitation, a point made by Regian (1986). A more recent study by Peterson, Kulhavy, and Stock (1991) demonstrated an interrelationship between



simultaneously-presented verbal and visual codes and proposed a model of "conjoint retention", in which activation spreads from map feature representations and images to corresponding verbal labels (or vice-versa).

### **Acquisition Under Unusual Circumstances**

Spatial learning can even occur under very unfavorable circumstances, as Allen (1988) showed by presenting subjects with environmental scenes in a jumbled order. Janssen and Michon (1973) explored variables that influence how people build internal representations of network-like structures resembling city road maps, and found that subjects are able to integrate piecemeal routes through networks into an internal representation of the entire network. Hanley and Levine (1983) found that people are able to integrate two separate paths into one map when given appropriate information. Recent research indicates that people can acquire configurational knowledge of a Virtual Reality environment (Regian, Shebilske, & Monk., 1992).

We report on two experiments which addressed the issue of whether the functional characteristics of configurational knowledge derived under various conditions are similar. Experiment 1 established norms for supporting materials used in Experiment 2. Subjects in Experiment 2 first learned the layout of a large-scale environment. This large-scale environment was either a real university campus or an artificial environment which the subject learned either by viewing a maplike depiction or by reading a verbal description. We refer to real-world environments as "naturally acquired", while both depicted and described environments are said to have been acquired "artificially". After learning an environment, subjects performed tasks which require knowledge of the spatial characteristics of that environment.

### **EXPERIMENT 1**

The purpose of Experiment 1 was to provide two types of normative information we needed to develop the concept and design of Experiment 2, although the issues involved have intrinsic interest as well. Specifically, we intended to determine if subjects would agree about what constitutes a prototypical environmental configuration, and which sites subjects consider likely or essential parts of a prototypical configuration.

In addition, we wanted to decide which of two possible fictitious environments (a rural town or an amusement park) would generate greater between-subject agreement regarding prototypical clustering. If subjects share a common prototype for the configuration of certain environments, this should be reflected in substantial agreement across subjects. For the purposes of Experiment 2, an average configuration of a fictitious environment, as determined by a multidimensional scaling (MDS) analysis of subject data, will only be meaningful if subjects are in substantial agreement. Since the

fictitious configuration cannot be compared to any external referent, the most important measure of prototypicality is probably the average correlation coefficient between initial subject data and the final MDS solution matrix.

Finally, we intended objectively to identify buildings that are highly familiar to University of Pittsburgh students, using a free-recall task.

## **Method**

### **Subjects**

Subjects for this Experiment were 5 female and 8 male students from the University of Pittsburgh between the ages of 18 and 24. All subjects were students in an introductory psychology course and participated in the study for course credit. All subjects had been at the University of Pittsburgh campus for approximately six months.

### **Materials**

Each subject was provided with a pencil and a set of printed materials which included a blank sheet of paper for recording the names of University of Pittsburgh buildings during free recall; a list of 25 amusement park sites (e.g., merry-go-round, roller coaster, refreshment stand, picnic area), each of which was to be rated on likelihood of occurrence in an amusement park; a set of 25 index cards, each containing an amusement park site label, to group into clusters; a list of 25 rural town sites (e.g., gun shop, feed supplier, church, diner), each of which was to be rated on likelihood of occurrence in a rural town; and a set of 25 index cards, each containing a rural town site label, to group into clusters.

**Procedure.** Upon arriving in the experimental room, subjects were instructed to free recall and write down as many names of University of Pittsburgh buildings as possible in 10 minutes. When they finished with this task, they received a list of sites (half received amusement park sites first, half received rural town sites first), and were instructed to rate each site on its "likelihood of occurrence" in either a typical amusement park or rural town, whichever was appropriate. Ratings were made on a scale from 1 (highly unlikely) to 10 (highly likely).

Next, subjects received the same list of sites on index cards, one site per card, and were instructed to produce not more than five clusters of sites they would expect to find near each other in a typical amusement park/rural town. They completed both the rating and card-sorting exercises with one environment, the rural town or the amusement park, before repeating both tasks for the other environment.

## Results

Subjects recalled an average of 16.4 names of buildings from the University of Pittsburgh campus. Eight buildings that were recalled by at least 11 of the subjects were selected for use in Experiment 2.

Table 1 gives likelihood ratings by subject for the amusement park sites. Average site ratings ranged between 4.6 and 10. The overall average likelihood rating for

amusement park sites was 7.71 (average  $SD = 1.61$ ). There was an inverse relationship between average likelihood rating and variability,  $r = -.83$ ,  $p < .01$ , which means that subjects agreed strongly on which sites are highly likely to occur at an amusement park.

Average site ratings for the rural town ranged from 3.3 to 10. The overall average likelihood rating was 6.92 (average  $SD = 2.09$ ). Although there was also an inverse relationship between average likelihood rating and variability,  $r = -.53$ ,  $p < .10$ , it was not as strong as for the amusement park to the site labels as given in Table 1. The amusement park solution accounted for 48% of the variance in the data,  $r = .69$ ,  $p < .01$ . The rural town solution accounted for 32% of the variance in the data,  $r = .57$ ,  $p < .05$ .

## Discussion

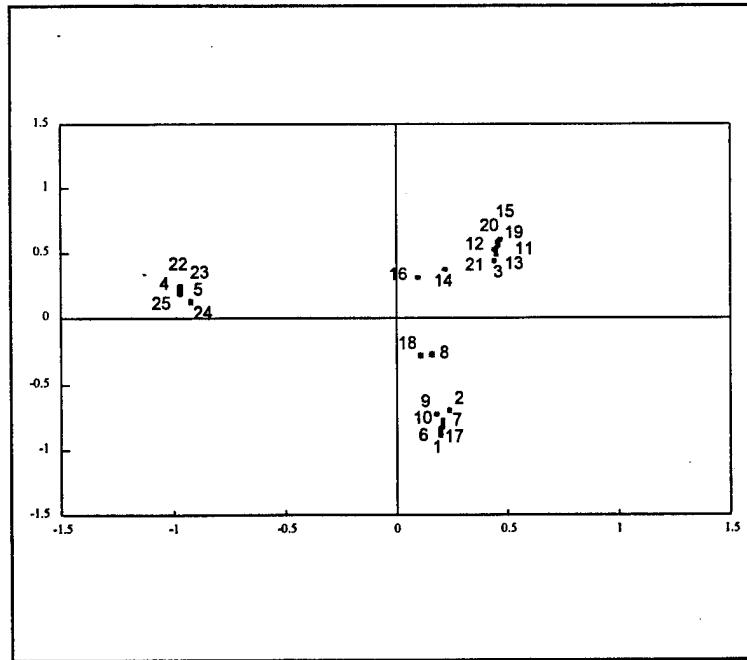
We found in Experiment 1 that subjects can agree on what constitutes a typical environmental configuration, and we were able to capture the configuration and use it in Experiment 2 to build an artificial environment. We also gathered subjects' likelihood ratings to use in Experiment 2 as a measure of schema-expectancy for sites in the appropriate environment.

We selected the amusement park, rather than the rural town, as the experimental environment for use in Experiment 2. There were a number of reasons for this choice. First, there was greater agreement between subjects as to the typical configuration of the amusement park. There was also greater agreement as to the likelihood of the amusement park sites than the rural town sites (although this may partly reflect our choice of sites), and the average likelihood ratings were higher for the amusement park. An examination of Figure 1 makes it apparent that site clusters were visually coherent in the amusement park. These clusters were also semantically meaningful: they can be summarized accurately and conveniently as rides, booths, shows, funhouses, and human services.

We were also able objectively to identify eight University of Pittsburgh buildings that were recalled by at least 11 of 13 students, and were therefore sufficiently familiar to undergraduate Psychology students to suit our purposes in Experiment 2.

**Table 1**  
**Likelihood Ratings for the Amusement Park**

Site	Subject Number													Avg.	SD
	1	2	3	4	5	6	7	8	9	10	11	12	13		
Refreshment stand	10	10	10	10	10	10	10	10	10	10	10	10	10	10.00	0.00
Ticket booth	10	10	10	10	10	10	10	9	10	10	10	10	10	9.92	0.27
Parking lot	10	10	10	10	10	10	10	10	8	10	10	10	10	9.85	0.53
Merry-go-round	8	10	10	10	10	10	10	9	10	10	10	10	10	9.77	0.58
Roller coaster	8	10	8	10	10	10	10	9	10	10	10	10	10	9.62	0.74
First aid station	10	10	8	10	9	10	10	9	7	9	10	10	10	9.38	0.92
Souvenir shop	9	10	9	9	9	10	8	8	10	9	10	8	10	9.15	0.77
Bumpercars	10	10	7	10	9	9	9	8	9	7	10	10	10	9.08	1.07
Ferris wheel	6	10	10	9	10	9	6	9	8	10	10	7	10	8.77	1.48
Haunted house	8	10	5	9	10	8	7	8	10	9	10	9	10	8.69	1.43
Picnic area	8	10	9	7	10	5	7	7	9	9	10	6	10	8.23	1.62
Lost and found	10	10	6	10	8	6	4	8	6	10	10	7	10	8.08	2.02
Water log ride	7	9	7	7	9	3	5	7	10	8	10	7	9	7.54	1.91
Dart throwing	8	10	9	5	7	3	10	7	8	7	5	5	10	7.31	2.20
Basketball throw	8	9	8	5	7	6	5	7	10	8	5	6	10	7.23	1.72
Sledgehammer	10	10	9	6	9	10	5	7	8	6	10	1	2	7.15	2.93
Shooting gallery	9	10	9	6	6	6	5	6	4	8	7	6	10	7.08	1.86
Band stand	7	10	5	6	5	7	5	5	9	6	7	6	10	6.77	1.76
Hoop tossing	8	10	6	7	7	2	10	6	8	5	5	5	8	6.69	2.13
Guess your weight	10	10	8	1	8	7	5	6	10	8	5	2	2	6.31	3.02
Salt/pepper shaker	2	10	9	7	9	5	4	6	10	7	5	2	4	6.15	2.68
Mirror maze	5	9	3	5	9	3	4	6	9	5	5	5	5	5.62	2.02
Super slide	5	7	5	4	6	3	5	5	5	7	8	1	4	5.00	1.75
Parachute drop	7	8	4	8	9	1	3	5	1	1	5	6	4	4.77	2.66
Puppet show	7	8	1	1	7	2	4	4	4	6	5	4	7	4.62	2.24



**Figure 1. MDS solution for the amusement park.**

## EXPERIMENT 2

The major purpose of Experiment 2 was to determine whether measures of configurational knowledge obtained from artificially-acquired environments are predictive of performance measures of configurational knowledge obtained from real-world environments.

Human flexibility appears to extend to performance as well as acquisition. A variety of methods and measures has been used to quantify individual differences in the

accuracy of configurational knowledge and in the speed of access to configurational knowledge. These include distance judgment tasks (e.g., Hirtle & Jonides, 1985); pointing tasks (e.g., Sholl, 1987; Lindberg & Garling, 1983); plotting tasks (e.g., Blades, 1990; Shute, 1984); free recall of sites (e.g., Hirtle & Jonides, 1985); map sketching (Gale, Golledge, Pellegrino, & Doherty, 1990); and reaction times, to examine spatiotemporal priming effects (e.g., Clayton & Habibi, 1991; McNamara, et al., 1989). From among this wide variety of measures, we selected a set of measures that appeared most suited to our purpose, including free recall of sites, pointing, and distance estimation. First, we predicted that subjects should be able to recall locations from the environment. Although such landmark knowledge does not in itself indicate that the subject has a configurational representation, it is an apparent prerequisite for configurational knowledge. We further predicted that subjects would be able to perform the pointing task with relative speed and accuracy. Finally, we predicted that subjects would be able to estimate relative distances between locations consistently. If so, a MDS analysis would recreate the environmental configuration with high intersubject agreement.

In addition, one secondary purpose of this experiment was to explore the possibility that prototypically-configured artificial environments are easier to learn than randomly-configured artificial environments. This hypothesis stems from the supposition that supplying subjects with categorical as well as spatial cues should increase learning relative to spatial cues alone. The two artificial environments used in this experiment were identical in all respects except for the assignment of labels to sites. Any learning and performance differences between prototypically- and randomly-configured artificial environments are attributable to the importance of prototypicality. Moreover, the manner in which subjects cluster sites during a free recall task should reflect whether subjects prefer to use spatial proximity or semantic similarity as primary recall cues. Spatial clustering, given the availability of clear semantic categories, would tend to support the notion that configurational knowledge is spatial in nature.

Another secondary purpose was to compare recall of sites with high schema-expectancy to recall of sites with low schema-expectancy. It is not clear what to expect from this comparison. Salmaso, Baroni, Job, and Peron (1983) proposed a theory that differentially relates schema-expectancy to intentional and incidental learning. Briefly, they proposed that low-expectancy items generally are recalled better than high-expectancy items when learning is intentional, because they receive more attention and processing. Conversely, high-expectancy items are better recalled than low-expectancy items when learning is incidental, because pure recall is supplemented by plausible inference. Their theory might be interpreted as predicting that in an intentional learning situation such as the present one, low schema-expectancy items (which presumably correspond to Salmaso, et al.'s "variable" items, although an exact correspondence is debatable) items might actually be recalled better than high schema-expectancy items

(which presumably correspond to Salmaso, et al.'s "structural" items). On the other hand, it is difficult to imagine trying to describe or recall a traditional American amusement park setting without mentioning a roller coaster or merry-go-round, simply because these rides are high schema-expectancy.

## **Method**

### **Subjects**

Subjects in this experiment were 8 female and 16 male students at the University of Pittsburgh between the ages of 18 and 22. All participated in the study for credit in an introductory psychology course. All subjects had been at the University of Pittsburgh campus for approximately seven months.

### **Materials**

The experiment was performed entirely on IBM PC XT microcomputers with standard CRT display characteristics. The standard IBM keyboard was used for response input, although the numeric keypad was redefined to perform the pointing function. Software for the experiment was developed at the Learning Research and Development Center. Response latency was recorded automatically and was accurate to 10 msec.

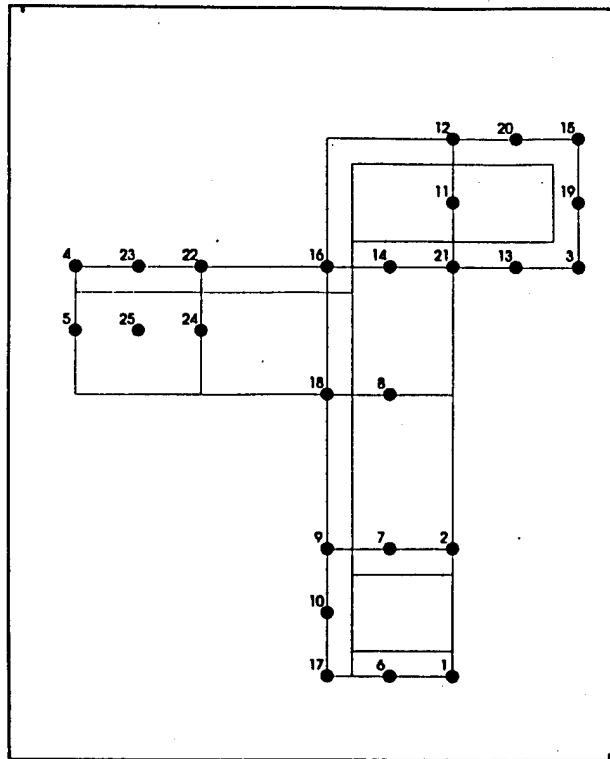
The prototypically-configured amusement park was derived from the MDS output for the amusement park co-occurrence matrices in Experiment 1. Figure 2 shows the prototypical amusement park configuration used in Experiment 2. Figure 2 was derived from Figure 1, and the site numbers correspond to the same sites as those in Figure 1.

The randomly-configured amusement park was derived by randomly reassigning site labels to locations on the amusement park grid. Each configuration of the amusement park contained 25 sites.

Each amusement park map was divided into seven sections, which were displayed in pictorial form, one section at a time. Subjects could move between sections using the directional keys on the numeric keypad. Decomposition of the environment into several separate sections should require considerable cognitive integration for a subject to achieve configurational knowledge.

### **Procedure**

During the acquisition phase, subjects explored the environment at will, moving back and forth between parts, until they decided they were ready to begin the assessment phase. Subjects' experience as students on the University of Pittsburgh campus



**Figure 2. Prototypical amusement park configuration.**

constituted the real-world acquisition phase.

We used four tasks to assess configurational knowledge in each condition. The first was free recall. In the real-world condition, subjects free-recalled as many building names as they could think of from the University of Pittsburgh campus. No criterion level of recall was set. In the artificial acquisition conditions, subjects were required to recall any 12 or more site labels to proceed further. If they failed to recall at least 12 items, they were told that they had failed the recall test and were then returned to the amusement park environment for further exploration.

We formed 16 random pairings of the campus building sites identified in Experiment 1 and used them to create sixteen pointing trials for the real-world condition.



Presentation order for the pointing trials was random with the constraint that no pair was presented twice in the same order. For the artificial conditions, we used the eight sites rated highest in likelihood by subjects in Experiment 1. These were the refreshment stand, ticket booth, parking lot, merry-go-round, roller coaster, first aid station, souvenir shop, and bumpercars. We randomly formed sixteen pairs of these sites, then presented them to subjects in random order, with the constraints that no pair could occur twice in the same order and that each of the eight possible pointing directions was represented twice. Thus, subjects performed sixteen pointing trials for each of the artificial acquisition conditions. The numeric keypad on the right part of the keyboard was adapted for this task. The center key (the 5) served as the home key, while pressing any of the other eight keys (1 through 9) indicated the presumed direction to another site. The pointing task procedure was similar for all conditions. Subjects were asked to imagine that they were at a given site facing another given site, and were to press the home key when they had achieved this. They were then to point (by keypress) at the third site as quickly as possible.

The distance-estimation task was essentially identical in each of the conditions. We presented subjects with all possible nonredundant pairs (28 pairs) of the 8 experimental locations selected for each condition, and they rated the distance between each pair on a 1-9 scale, where "1" represented the pair that was closest together and "9" represented the pair that was farthest apart.

For the real-world plotting task, subjects were given a sheet which showed an accurate street layout of the University campus. Two locations, which were not among the experimental sites, were marked on the map and identified, to help subjects orient. These were the campus book center and Pitt Stadium. The sheet contained no other information. Subjects plotted the locations of the eight experimental buildings. In the artificial conditions, subjects were given an accurate path layout of the entire amusement park. Two locations, which were not among the experimental sites, were marked on the map to help subjects orient. These were the picnic area and the strongman sledgehammer bell. Subjects were asked to plot the locations of the eight experimental sites.

Subjects received extensive instructions for performing each task. The assessment task sequence in every case was free recall, pointing, distance estimation, and plotting. All subjects performed the tasks of the real-world condition first.

## **Results**

The design of this experiment allowed us to consider alternative analyses. All 24 subjects participated in the real-world condition, but only half (12 subjects) participated in each of the prototypically- and randomly-clustered artificial acquisition conditions.

Comparisons between prototypical and random acquisition conditions were thus between subjects, and were carried out by independent-sample t-tests. Simultaneous comparisons among all three conditions were carried out as if they represented three separate unequal-sized groups ( $n_1 = 12$ ,  $n_2 = 12$ ,  $n_3 = 24$ ) in a fixed-effects ANOVA model. This procedure was chosen as a conservative method of dealing with the partial dependence between groups, and because it allowed pairwise comparisons. We also did an alternative analysis by treating the prototypical and random acquisition conditions as a single artificial acquisition condition and comparing this condition to the real-world acquisition condition with paired-sample t-tests. In every instance this approach led to the same conclusions as the ANOVA model, but at the cost of making the relationships among the three conditions less obvious.

### Learning

It took subjects an average of 1.33 attempts to learn the prototypically-clustered map well enough to meet the criterion, compared to 1.83 attempts for randomly-clustered map. This difference was not reliable,  $t(22) = 1.34$ ,  $p = .10$ .

Subjects required an average of 12 minutes 29 seconds to learn the prototypically-clustered map, compared to 11 minutes 3 seconds for the randomly-clustered map. This difference also was not reliable,  $t(22) = 0.76$ .

### Recall

Subjects recalled an average of 20.67 items in the prototypical condition, 21.25 items in the random condition, and 16.96 items in the real-world condition. The difference in recall between the two artificial acquisition conditions was not statistically reliable,  $t(22) = 0.43$ . Subjects recalled reliably fewer real-world items, compared to either artificial acquisition condition,  $F(2, 45) = 4.78$ ,  $p < .05$ .

Table 2 presents the amusement park sites, along with their average likelihood ratings (from Experiment 1) and the number of subjects in Experiment 2 who recalled each site. Recall data are presented separately for all subjects, subjects in the prototypically-configured condition, and subjects in the randomly-configured acquisition condition. The data show no apparent relationship between likelihood ratings and recall levels. The Pearson product-moment correlation coefficient between likelihood rating and total recall was .40,  $p > .05$ . In the prototypically-configured condition, the correlation between likelihood rating and recall was .34,  $p > .10$ , and in the randomly-configured condition,  $r$  was .29,  $p > .10$ .

## Clustering in recall

We used the Adjusted Ratio of Clustering (ARC) score (Gerjouy & Spitz, 1966; Roenker, Thompson, & Brown, 1971) to quantify clustering in the free-recall data. The ARC quantifies the degree to which free recall clusters correspond to a priori categories that the experimenter considers likely. An ARC of 0 indicates chance clustering, while an ARC of 1 indicates perfect adherence to the hypothetical categories delineated by the experimenter. We were interested in both semantic clustering and spatial clustering. Semantic clustering, in the present context, would be characterized by observation of recall clusters which correspond to groups of site labels that go together by virtue of the prototypically-configured condition, so these data were not included in the ARC analysis). Evidence of semantic clustering at recall in the random acquisition condition would indicate that subjects prefer to rely on a semantic recall strategy in these circumstances, while spatial clustering at recall would indicate preference for a spatial recall strategy.

There were five semantic clusters. Cluster 1 included the parking lot, picnic area, first aid station, lost and found booth, ticket booth, refreshment stand, and souvenir shop. Cluster 2 included the band stand and puppet show. Cluster 3 included the haunted house and mirror maze. Cluster 4 included the bumper cars, ferris wheel, roller coaster, merry-go-round, parachute drop, water log ride, salt & pepper shakers, and super slide. Cluster 5 included the strongman sledgehammer bell, guess your weight booth, hoop tossing booth, dart throwing booth, shooting gallery, and basketball throw game.

There were also five spatial clusters. Cluster 1 included the basketball throw game, water log ride, mirror maze, shooting gallery, merry-go-round, ticket booth, and strongman sledgehammer bell. Cluster 2 included the band stand and parachute drop. Cluster 3 included the ferris wheel and souvenir shop. Cluster 4 included the dart throwing booth, roller coaster, super slide, hoop toss, picnic area, haunted house, parking lot, and first aid station. Cluster 5 included the refreshment stand, salt & pepper shakers, puppet show, lost & found booth, and guess your weight booth.

The results are clear. Subjects in the randomly-clustered acquisition condition had substantially higher scores for spatial clustering (.59) than for semantic clustering (.06). This difference was statistically reliable,  $t(11) = 3.19$ ,  $p = .004$ .

## Pointing

Average times to prepare for pointing in the prototypical, random, and real-world

**Table 2**  
**Likelihood Ratings and Recall Levels**

<u>Site Label</u>	N=13 <u>Avg. Likelihood</u>	N=24 <u>Recall</u>	N=12 <u>Recall</u>	N=12 <u>Recall</u>
Refreshment stand	10.00	18	8	10
Ticket booth	9.92	22	11	11
Parking lot	9.85	23	12	11
Merry-go-round	9.77	22	10	12
Roller coaster	9.62	23	11	12
First aid station	9.38	23	11	12
Souvenir shop	9.15	17	9	8
Bumpercars	9.08	19	10	9
Ferris wheel	8.77	23	12	11
Haunted house	8.69	20	9	11
Picnic area	8.23	19	9	10
Lost and found	8.08	18	10	8
Water log ride	7.54	19	8	11
Dart throwing	7.31	18	9	9
Basketball throw	7.23	24	12	12
Strongman hammer	7.15	19	10	9
Shooting gallery	7.08	20	9	11
Band stand	6.77	20	11	9
Hoop tossing	6.69	18	9	9
Guess your weight	6.31	18	9	9
Salt & pepper shaker	6.15	17	9	8
Mirror maze	5.62	19	9	10
Super slide	5.00	18	7	11
Parachute drop	4.77	20	9	11
Puppet show	4.62	20	11	9

conditions were 7.18 sec., 6.05 sec., and 6.65 sec., respectively. None of these differences was statistically reliable,  $F(2, 45) = 0.49$ ,  $p = .62$ .

Average reaction times to point in the prototypical, random, and real-world conditions were 2.56 sec., 3.17 sec., and 4.50 sec. respectively. Time required to point was longest for the real-world condition, followed by the random condition, and then the prototypical condition,  $F(2, 45) = 5.54, p = .007$ . All pairwise comparisons on this measure were reliable at the .05 level.

Pointing error for each trial ranged from 0 (no error) to 4 (pointing in the opposite direction). Average pointing error for the prototypical, random, and real-world conditions was 0.92, 1.16, and 0.90, respectively. These pointing errors were statistically equivalent, however,  $F(2, 45) = 1.12, p = .34$ . No pairwise comparisons were reliable at the .05 level.

### Plotting

Average plotting errors for the prototypical, random, and real world conditions were 1.59, 2.98, and 1.25 cm, respectively. If subjects in the prototypical condition based their plots on the cluster to which a site belonged rather than on the specific site location, they would have been expected to show an average plotting error of 2.63 cm. Subjects apparently were remembering the location of the site rather than just the cluster to which it belonged. The three conditions differed reliably,  $F(2, 45) = 4.18, p = .02$ . The only pairwise comparison which was not reliable at the .05 level was the one between the prototypical and real-world conditions,  $t(34) = 0.73$ .

Table 3 gives the correlations between each of these performance measures across conditions. In each case, the real-world condition performance measures are correlated with the corresponding performance measures from both the prototypically-clustered acquisition condition and the randomly-clustered acquisition condition. The table also includes correlations between the real-world performance measures and the measures derived when data from the prototypically- and randomly-clustered acquisition conditions are combined into an overall artificially-acquired condition index.

### Multidimensional Scaling

We used INDSCAL to perform a MDS on distance estimates from each of the three acquisition conditions, and generated a two-dimensional solution for each condition. In all three acquisition conditions, subjects' distance estimates produced solutions which appear accurately to reflect the actual configurations of locations. Figure 3 is a map of the University of Pittsburgh, showing the relevant locations. They include the Hillman Library (point 1), Litchfield Towers (point 2), William Pitt Union (point 3), Clapp Hall (point 4), David Lawrence Hall (point 5), Old Engineering Hall (point 6), Cathedral of Learning (point 7), and Benedum Hall (point 8). Figure 4 shows the solution plot for this real-world environment over all 24 subjects, while Figure 5 shows the solution plot

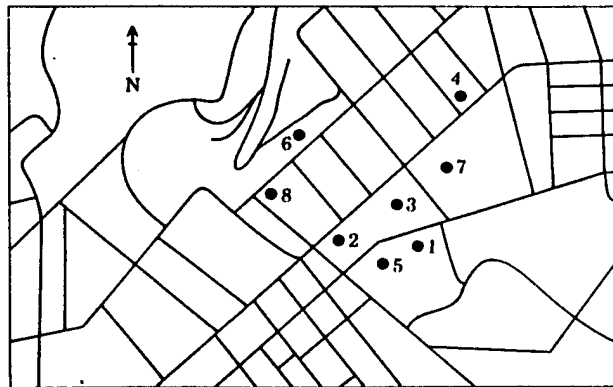
for the prototypically clustered amusement park, and Figure 6 shows the solution plot for the randomly-clustered amusement park. These plots include the bumpercars (point 1), souvenir shop (point 2), first aid station (point 3), roller coaster (point 4), merry-go-round (point 5), parking lot (point 6), ticket booth (point 7), and refreshment stand (point 8). Subjects in all three acquisition conditions were consistently and reliably able to estimate relative distances among locations accurately. As Table 4 shows, the correlations between MDS solution

**Table 3**  
**Correlations Between Performance Measures**

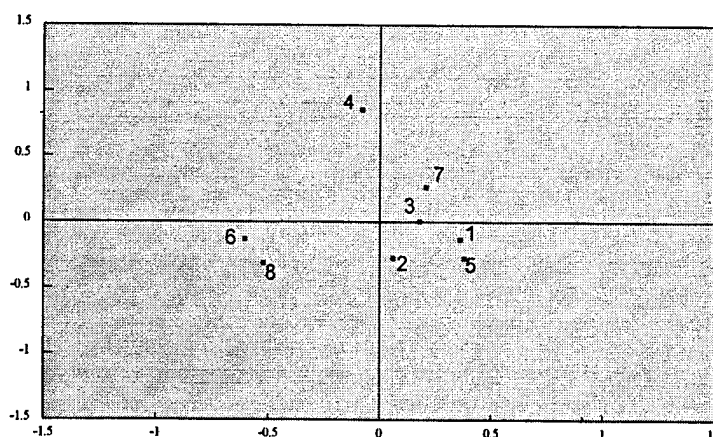
<u>Measures Correlated</u>	<u>n</u>	<u>Correlation</u>	<u>Sig. Level</u>
<u>Time to prepare.</u>			
Real world with: amusement park	24	.62	.01
(prototypical)	12	(.49)	>.10
(random)	12	(.86)	.01
<u>Time to point.</u>			
Real world with: amusement park	24	.45	.04
(prototypical)	12	(.26)	>.10
(random)	12	(.62)	.03
<u>Pointing error.</u>			
Real world with: amusement park	24	.40	.05
(prototypical)	12	(.38)	>.10
(random)	12	(.53)	.07
<u>Plotting error.</u>			
Real world with: amusement park	24	.82	.01
(prototypical)	12	(.30)	>.10
(random)	12	(.93)	.01
World plot			
error with: park pointing error	24	.54	.01
(prototypical)	12	(.55)	<.10
(random)	12	(.76)	.01

**Table 4**  
**Average Correlations Between Original Data and Solutions**

	$r$	$r^2$	$n$	$p$
<u>Real-world:</u>				
All subjects	.85	.73	24	<.01
Group 1 (proto)	.85	.74	12	<.01
Group 2 (random)	.86	.75	12	<.01
<u>Artificial:</u>				
Group 1	.92	.84	12	<.01
Group 2	.73	.60	12	<.01



**Figure 3. Grid map of the University of Pittsburgh**



**Figure 4. Real-world MDS solution, all subjects**

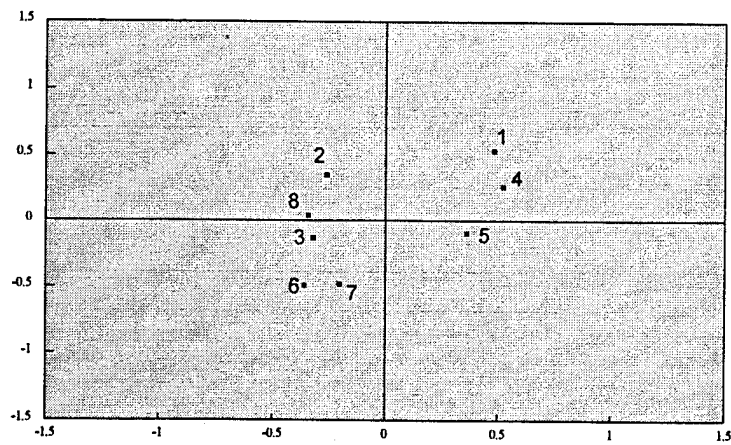
distances and actual distances were .94,  $p < .01$ , for the real-world condition; .70,  $p < .01$ , for the prototypical condition; and .91,  $p < .01$ , for the random condition.

Finally, the average subject correlation coefficient (a measure of the degree of intersubject agreement with the obtained solution) was .85,  $p < .01$ , for the real-world condition; .92,  $p < .01$ , for the prototypically-clustered artificial acquisition condition; and .73,  $p < .01$ , for the randomly-clustered artificial acquisition condition. The difference between the prototypical and random conditions was reliable,  $t(22) = 2.42$ ,  $p = .01$ .

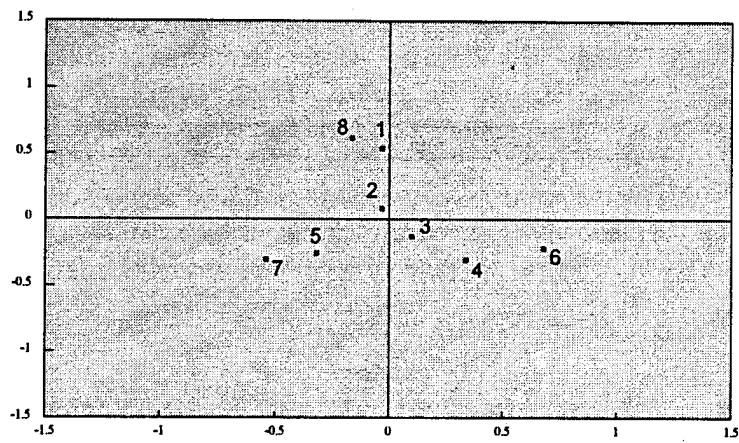
### Discussion

One implication of the results of Experiment 2 is that a computer-administered procedure could serve as a predictor of real-world spatial orientation by comparing performance on isomorphic computer-based and real. Two basic measures of spatial orientation, time to prepare for pointing and pointing error, were statistically equivalent across the real-world and the two artificial acquisition conditions. More importantly, we obtained strong correlations between corresponding performance measures from the real-world and the randomly-configured artificial environment conditions, ranging from .53 for pointing error to .93 for plotting error.





**Figure 5. MDS Solution for the prototypical amusement park**



**Figure 6. MDS solution for the random amusement park.**

There are at least two potential areas for research and application of the procedures developed in this research. The first involves assessing configurational knowledge of a real-world environment, which would only require instantiating the software with real-world locations. Our approach could be applied to training knowledge of specific environments. Thus, it could be useful to represent an actual environment for training individuals such as ambulance drivers and military field officers, who need fast and accurate knowledge to make rapid navigational decisions in situations where delays might have serious consequences. The approach might be suitable for both actual training and for diagnostic assessment during training. Additional research is required to assess transfer of the task to real-world environments in order to demonstrate the suitability of the procedure for this kind of application.

The second involves assessing the ability to acquire and use configurational knowledge of a real-world environment. It is our belief that the best predictor of performance on a task is performance on a carefully-designed analogue of the task. Moreover, the tasks and measures developed for this research appear suitable to validate a process model of access to configurational knowledge, much like Golledge, et al. (1985) used information about choice points to validate a model of how route information is encoded.

It is surprising that the correlations between corresponding performance measures in the real-world and prototypically-clustered conditions are lower than those between the real-world and randomly-clustered conditions. One possible explanation is that orienting in the prototypically-clustered condition was too easy for any strong relationship to emerge for individual differences in performance measures. This could mean that an artificial environment must approach real-world complexity to be predictive of real-world orientation skills. On the other hand, it could be that prototypically-configured artificial environments might be useful in predicting real-world performance under certain circumstances, for example when the real environment is itself configured according to some prototypical pattern. We were also surprised that the prototypically-configured condition did not lead to better performance on essentially all of the measures, relative to the randomly-configured condition. One simple explanation is that prototypicality is an effective memory aid primarily in incidental or weak learning situations, such as the Stevens and Coupe (1978) study, where memory was strongly supplemented by inference. The present study required intentional learning to the same specific criterion in both conditions. It is not easy, however, to reconcile this explanation with the fact that the prototypical condition resulted in worse, rather than roughly equal, performance.

It is perhaps somewhat surprising at first that prototypicality did not result in faster acquisition, because the situation superficially resembles learning a free-recall list made up of words that represent several distinctive semantic categories. Instead,

prototypicality produced only a statistically unreliable decrease in the average number of attempts needed for acquisition, while the total time required for learning was essentially identical to that for the random configuration. Subjects in the prototypically-configured condition tended to spend slightly more time learning the map before attempting to meet the criterion.

Upon reflection, however, the effect of prototypicality on acquisition appears reasonable. Free-recall lists don't usually require learning along a secondary dimension in addition to simply learning list items; here the analogy to free recall breaks down. The present task required subjects to learn spatial information as well, and the results suggest the possibility that the semantic learning actually interfered with spatial learning and vice versa. Semantically-similar site names had to be linked specifically with spatially-close locations; the situation could produce considerable interference. In the randomly-configured condition the semantically-similar items were not always spatially linked.

In addition, it may be that despite instructions that stressed clustering sites which would be "found close together", subjects either did not or could not exclude semantic considerations when forming their clusters. If the MDS subsequently configured what could be termed an "idealized" park based on mixed semantic and spatial (or even primarily semantic) information, rather than a spatially-prototypical park, the groupings might therefore lack certain important characteristics of prototypical configurations. For example, perhaps only different subsets of these clusters are ever actually configured together in a real park. The resulting clusters would have little psychological reality, in that no one expects them or notices if they are not there. Although subjects were able to accommodate the instructions, there may not be any real prototype of an amusement park in that nothing really "belongs" with anything else. This may be what is indicated by the spatial rather than semantic clustering.

In any event, the prototypicality manipulation was important for purposes of predicting real-world performance. A reasonable interpretation of this result must also take into account that the real-world environment used in these experiments (the University of Pittsburgh campus) is essentially randomly configured. There are no obvious semantic divisions which capture the organization of the campus. It may be, then, that each separate location had to be coded spatially in both the real-world and random conditions. In contrast, it may be that subjects learning the prototypically-configured condition had to deal with combined semantic knowledge and spatial knowledge, leading to different patterns of individual differences in the prototypically-configured condition. Moreover, it may be that learning an additional semantic component would also add to learning time, canceling out any benefit the prototypical configuration might otherwise have had on learning time. Subjects in the present experiment clearly showed spatial clustering, rather than semantic clustering, when the

spatial layout of the environment did not reflect the semantic categories of the locations. This supports the idea that configurational knowledge is primarily a spatially-coded aspect of environmental knowledge.

Schema-expectancy had no effect on recall probability when defined as the normative likelihood of a site's occurrence in an environment. Less-likely sites were recalled just as often as more-likely sites. One simple explanation for this is that "low" and "high" sites were not sufficiently different in schema-expectancy to yield an effect. It appears more likely, however, that the lack of effect is partly consistent with Salmaso, et al.'s (1983) theory of the interactions between intentional and incidental learning of materials that vary in schema-expectancy. The theory predicts relatively high recall of low schema-expectancy items, but also apparently predicts relatively lower recall of high schema-expectancy items. That there was no difference in recall suggests that the theory requires modification. One possible modification involves proposing a supplementary role for the degree to which a schema exists for the setting, that is, how strong the schema is. A schema would, in turn, provide for a very high level of association between a setting and particular items. In addition, Mandler (1984) has distinguished between the roles of schema-consistency and schema-relevance in recall. We asked subjects in Experiment 1 to rate schema-expectancy, which appears to be conceptually closer to relevance than to consistency. However, it is apparent that the relationship between the concepts of schema-relevance, schema-consistency, and schema-expectancy, as well as their interactions in intentional and incidental learning, are not well understood.

## References

- Allen, G.L. (1979). A developmental perspective on the structural organization of spatial knowledge. Unpublished doctoral dissertation, University of Pittsburgh.
- Allen, G.L. (1988). The acquisition of spatial knowledge under conditions of temporospatial discontinuity. Psychological Research, 50, 183-190.
- Anderson, J.R. (1983). The architecture of cognition. Cambridge, MA: Harvard University Press.
- Blades, M. (1990). The reliability of data collected from sketch maps. Journal of Environmental Psychology, 10, 327-339.
- Carroll, J. D., and Chang, J.J. (1970). Analysis of individual differences in multidimensional scaling via an N-way generalization of "Eckart-Young" decomposition. Psychometrika, 35, 283 - 311.
- Clayton, K. and Habibi, A. (1991). Contribution of Temporal Contiguity to the Spatial Priming effect. Journal of Experimental Psychology: Learning, Memory, and Cognition, 17, 263-271.
- Easton, R.D., and Bentzen, B.L. (1987). Memory for verbally presented routes: A comparison of strategies used by blind and sighted people. Journal of Visual Impairment & Blindness, March, 100-105.
- Evans, G. W., Marrero, D. G., & Butler, P. A. (1981). Environmental learning and cognitive mapping. Environment and Behavior, 13, 83 -104.
- Evans, G. W. and Pezdek, K. (1980). Cognitive mapping: Knowledge of real-world distance and location information. Journal of Experimental Psychology: Human Learning and Memory, 6, 13-24.
- Foley, J.E., and Cohen, A.J. (1984). Working mental representations of the environment. Environment and Behavior, 16, 713-729.
- Foos, P.W. (1980). Constructing cognitive maps from sentences. Journal of Experimental Psychology: Human Learning and Memory, 6, 25-38.
- Franklin, N. and Tversky, B. (1990). Searching imagined environments. Journal of Experimental Psychology: General, 119, 63-76.
- Gale, N., Golledge, R.G., Pellegrino, J.W., and Doherty, S. (1990) The acquisition and integration of route knowledge in an unfamiliar neighborhood. Journal of Environmental Psychology, 10, 3-25.
- Gauvain, M. and Rogoff, B. (1986). Influence of the goal on children's exploration and memory of large-scale space. Developmental Psychology, 22, 72-77.
- Glushko, R.J., and Cooper, L.A. (1978). Spatial comprehension and comparison processes in verification tasks. Cognitive Psychology, 10, 391-421.
- Gerjouy, I.R., and Spitz, H.H. (1966). Associative clustering in free recall: Intellectual and developmental variables. American Journal of Mental Deficiency, 70, 918-927.

- Golledge, R., Smith, T., Pellegrino, J., Doherty, S., and Marshall, S. (1985). A conceptual model and empirical analysis of children's acquisition of spatial knowledge. Journal of Environmental Psychology, 5, 125-152.
- Hanley, G.L., and Levine, M. (1983). Spatial problem solving: The integration of independently learned cognitive maps. Memory & Cognition, 11, 415-422.
- Hardwick, D.A., McIntyre, C.W., and Pick, H.L. (1976). The content and manipulation of cognitive maps in children and adults. Monographs of the Society for Research in Child Development, 41, Serial No. 166.
- Hazen, N.L., Lockman, J.J., and Pick, H.L., Jr. (1978). The development of children's representations of large-scale environments. Child Development, 4, 71-115.
- Herman, J.F., Kail, R.V., and Siegel, A.W. (1979). Cognitive maps of a college campus: A new look at freshman orientation. Bulletin of the Psychonomic Society, 13, 183-186.
- Herman, J.F., Blomquist S.L., and Klein, C.A. (1987). Children's and adults' cognitive maps of very large unfamiliar environments. British Journal of Developmental Psychology, 5, 61-72.
- Herman, J.F., Cachuela, G.M., and Heins J.A. (1987). Children's and adults' long-term memory for spatial locations over an extended time period. Developmental Psychology, 23, 509-513.
- Hirtle, S.C., and Jonides, J. (1985). Evidence of hierarchies in cognitive maps. Memory & Cognition, 13, 208-217.
- Janssen, W.H., and Michon, J.A. (1973). The internal representation of simple geometric networks: Experiments with sequential part presentation. Acta Psychologica, 37, 197-213.
- Kosslyn, S.M. (1980). Image and Mind. Cambridge, MA: Harvard University Press.
- Levine, M., Jankovic, I.N., and Palij, M. (1982). Principles of spatial problem solving. Journal of Experimental Psychology: General, 111, 157-175.
- Lindberg, E., and Garling, T. (1981a). Acquisition of locational information about reference points during locomotion with and without a concurrent task: Effects of number of reference points. Scandinavian Journal of Psychology, 22, 109-115.
- Lindberg, E., and Garling, T. (1981b). Acquisition of locational information about reference points during blindfolded and sighted locomotion: Effects of a concurrent task and locomotion paths. Scandinavian Journal of Psychology, 22, 101-108.
- Lindberg, E., and Garling, T. (1983). Acquisition of different types of locational information in cognitive maps: Automatic or effortful processing? Psychological Research, 45, 19-38.
- Mandler, J.M. (1984). Stories, scripts, and scenes: Aspects of schema theory. Hillsdale, NJ: Erlbaum.

- Mani, K., and Johnson-Laird, P.N. (1982). The mental representation of spatial descriptions. Memory & Cognition, 10, 181-187.
- McNamara, T.P., Altarriba, J., Bende, M., Johnson, S.C., and Clayton, K.N. (1989). Constraints on priming in spatial memory: Naturally learned versus experimentally learned environments. Memory & Cognition, 17, 444-453.
- Paivio, A. (1986). Mental representations: A dual-coding approach. New York: Oxford University Press.
- Paivio, A. (1979). Imagery and verbal processes. New York: Holt, Rinehart, and Winston.
- Peterson, S.E., Kulhavy, R.W., Stock, W.A., and Pridemore, D.R. (1991). How map features cue associated verbal content. Bulletin of the Psychonomic Society, 29, 158-160.
- Presson C.C. and Hazelrigg, M.D. (1984). Building spatial representations through primary and secondary learning. Journal of Experimental Psychology: Learning, Memory, and Cognition, 10, 716-722.
- Presson, C.C., DeLange, N., and Hazelrigg, M.D. (1989). Orientation specificity in spatial memory: What makes a path different from a map of the path? Journal of Experimental Psychology: Learning, Memory, and Cognition, 15, 887-897.
- Pylyshyn, Z.W. (1984). Computation and cognition. Cambridge, MA: MIT Press.
- Regian, J.W. (1986). Assessment of configurational knowledge of naturally- and artificially-acquired large-scale space. Unpublished doctoral dissertation, University of California, Santa Barbara.
- Regian, J.W., Shebilske, W.L., and Monk, J.M. (1992). A preliminary empirical evaluation of virtual reality as an instructional medium for visual-spatial tasks. Journal of Communication, 42, 136-149.
- Roenker, D.L., Thompson, C.P., and Brown, S.C. (1971). Comparison of measures for the estimation of clustering in free recall. Psychological Bulletin, 76, 45-48.
- Sholl, M.J. (1987). Cognitive maps as orienting schema. Journal of Experimental Psychology: Learning, Memory, and Cognition, 13, 615-628.
- Salmaso, P., Baroni, M. R., Job, R., and Peron, E. M. (1983). Schematic information, attention, and memory for places. Journal of Experimental Psychology: Learning, Memory, and Cognition, 9, 263-268.
- Shute, V. (1984). Characteristics of cognitive cartography. Unpublished doctoral dissertation, University of California, Santa Barbara.
- Siegel, A.W., and White, S.H. (1975). The development of spatial representations of large-scale environments. In H.W. Reeve (Ed.), Advances in child development and behavior, 10, New York, NY: Academic Press.
- Stasz, C. (1979). Ability, procedure, and strategy differences in knowledge acquisition from maps. Unpublished doctoral dissertation, University of California, Los Angeles.

- Stevens, A., and Coupe, P. (1978). Distortions in judged spatial relations. Cognitive Psychology, 10, 422-437.
- Thorndyke, P.W., and Stasz, C. (1980). Individual differences in procedures for knowledge acquisition from maps. Cognitive Psychology, 12, 137-175.
- Thorndyke, P.W. and Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. Cognitive Psychology, 14, 560-589.
- Tversky, B. (1981). Distortions in memory for maps. Cognitive Psychology, 13, 407-433.
- Wetherell, A. (1979). Short-term memory for verbal and graphic route information. In Proceedings of the human factors society--23rd annual meeting. Santa Monica, CA: Human Factors Society.